

# *Superconducting Cavity Development at FNAL*

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All Experimenters Meeting

3 May 2004

# Two 3.9GHz Designs

TM<sub>110</sub> mode *"CKM"*

*K<sup>+</sup> RF separator for K<sup>+</sup> → πνν̄*

*Bunch profile measurement at zero crossing*

$$P_{\perp} = 5\text{MV/m} \quad B_{\text{MAX}} = 80\text{mT} \quad E_{\text{MAX}} = 18.6\text{MV/m}$$



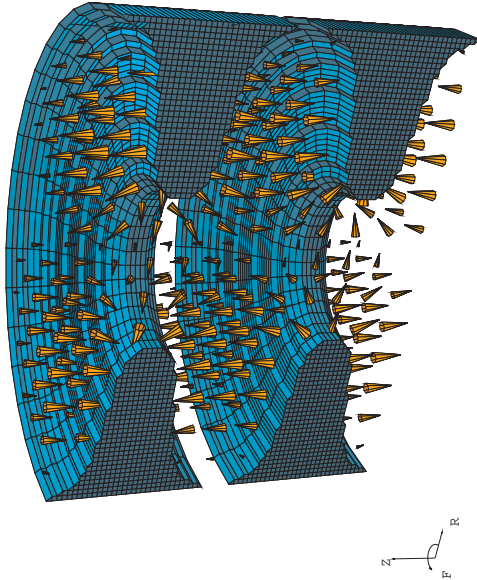
$$E_{\text{ACC}} = 14\text{MV/m} \quad B_{\text{MAX}} = 73\text{mT} \quad E_{\text{MAX}} = 31.6\text{MV/m}$$

TM<sub>010</sub> mode *"3<sup>rd</sup> Harmonic"*

*Linearize acceleration within bunch before compression for better emittance*

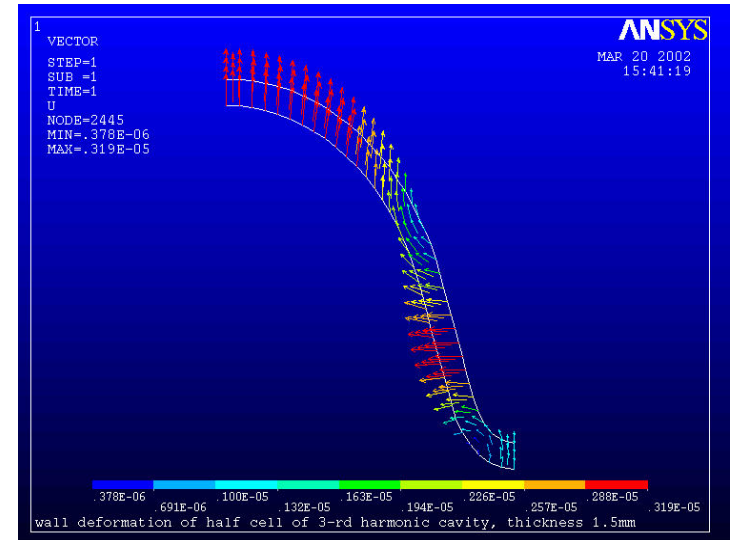
TM<sub>010</sub> cavity in TESLA bunch compression reduces energy loss and a 2-stage system could permit compression to < 300μm, reducing the 'banana effect' -  
Piot & Decking, FNAL TM-2235

# RF Design



- Basic electromagnetic design done with MAFIA, HFSS, lumped equivalent element methods
- Interface to mechanical FEMs (ANSYS, IDEAS) custom built

Lorentz force detuning calculated  $\Delta f = 770\text{Hz}$  for CKM cavity of 1.6mm thick wall with free ends; measured at  $\Delta f = 728\text{Hz}$



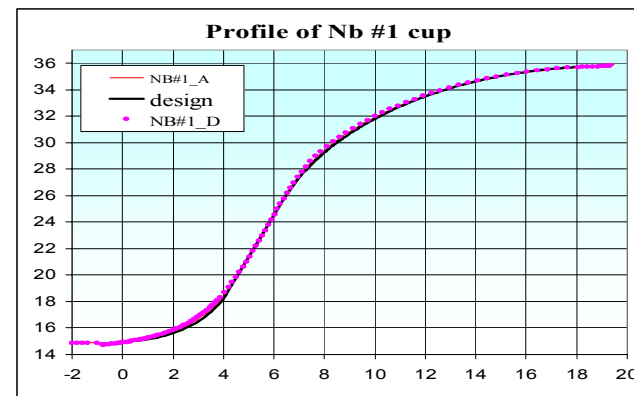
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# Cavity Manufacture



*We purchase pure ( $RRR=300$ ) Nb sheet from industry  
Eddy current scanning has kindly been done for us by DESY,  
we are commissioning an eddy current scanner now  
Stamp and e-beam weld near FNAL under clean conditions  
RF measurements and profile measurements of 1/2 cells on site  
We have an on-site vacuum bake facility (1000 C) to remove  $H_2$   
and anneal - have not done Titanium gettering  
Field flatness tuning on site  
BCP Acid etch has kindly been done for us by JLab, to be  
done in collaboration with Argonne  
On-site high pressure rinse with  $18M\Omega H_2O$*

*Also are contracting with Advanced Energy  
Systems to build a few cavities*



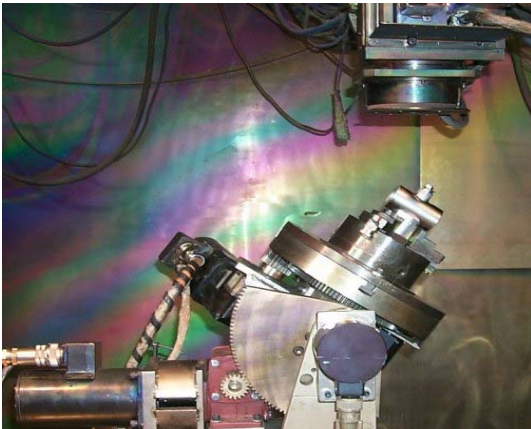
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# Cavity Manufacture

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Eddy Current Scanner donated by JLAB



E-Beam welding at Sciaky



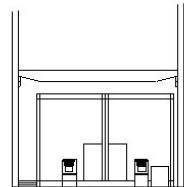
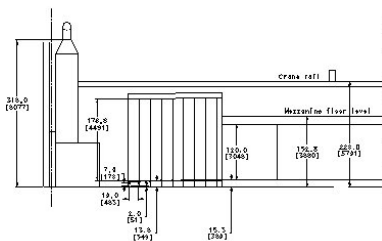
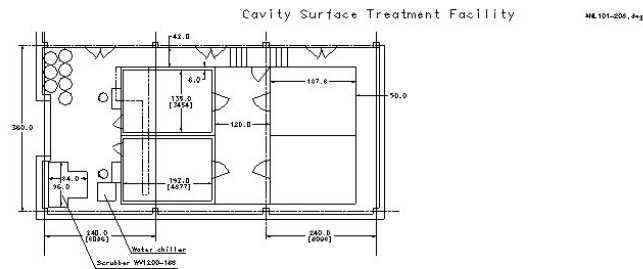
1000°C Vacuum Oven

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# Chemistry

***Short term: Existing  
ANL facility*** ➡



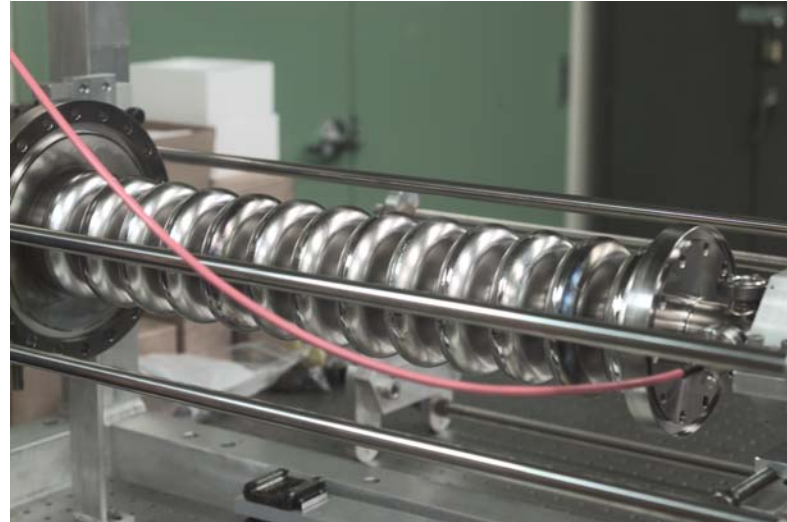
***Long term: Joint  
ANL/FNAL facility*** ↗



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# Cavities Produced

Nine  $TM_{110}$  mode cavities have been made, mostly shorter structures, but there is one full 13 cell prototype

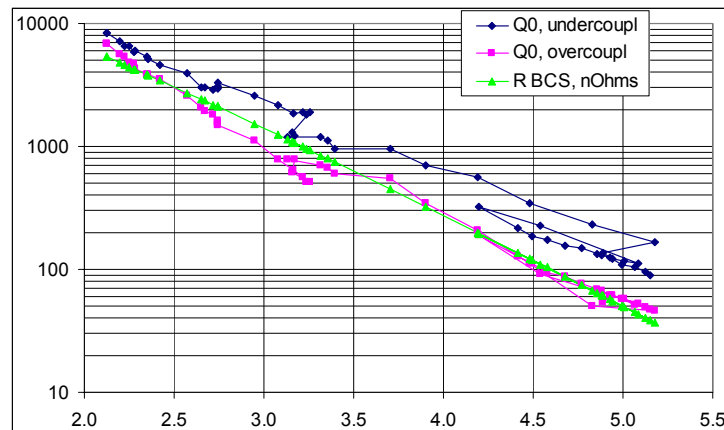
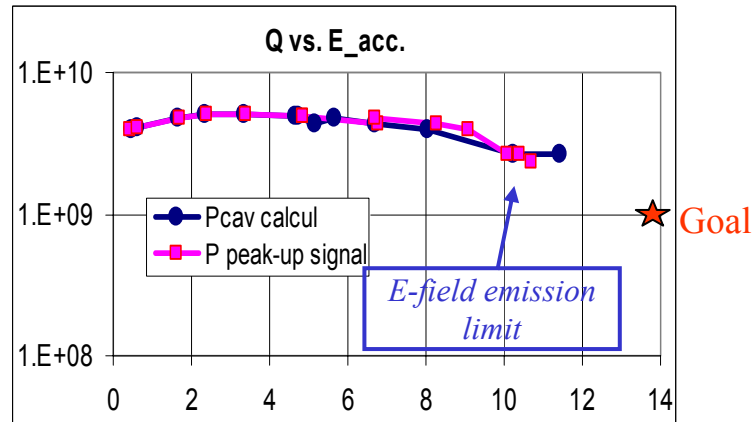


In addition to the copper  $TM_{010}$  mode cavity shown earlier, a 3 cell has been made in niobium and a full 9 cell prototype is in production now

# Cold Test Results ( $TM_{010}$ )

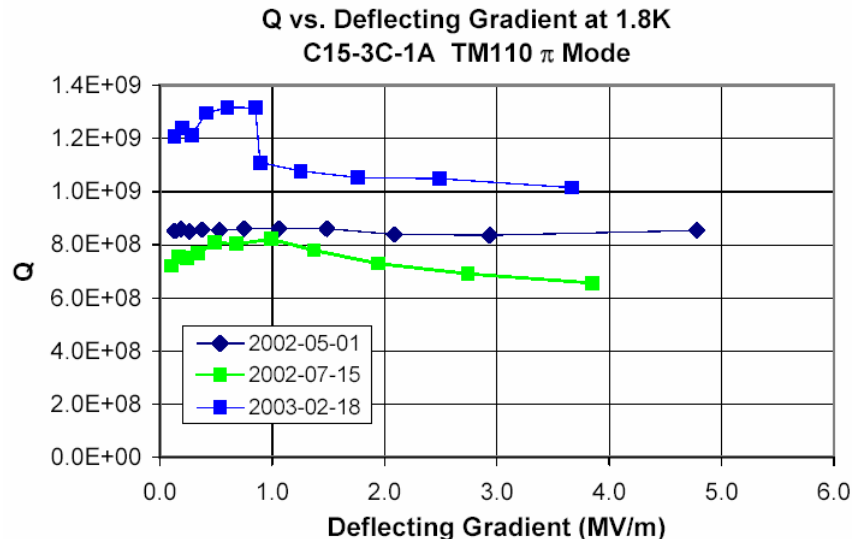


140  $\mu\text{m}$  BCP,  
heat treatment  
and HPR





# Cold Test Results (TM<sub>110</sub>)



Most cold tests done with 3 cell cavity -  
Acid etch facilities need upgrade for 13 cell test

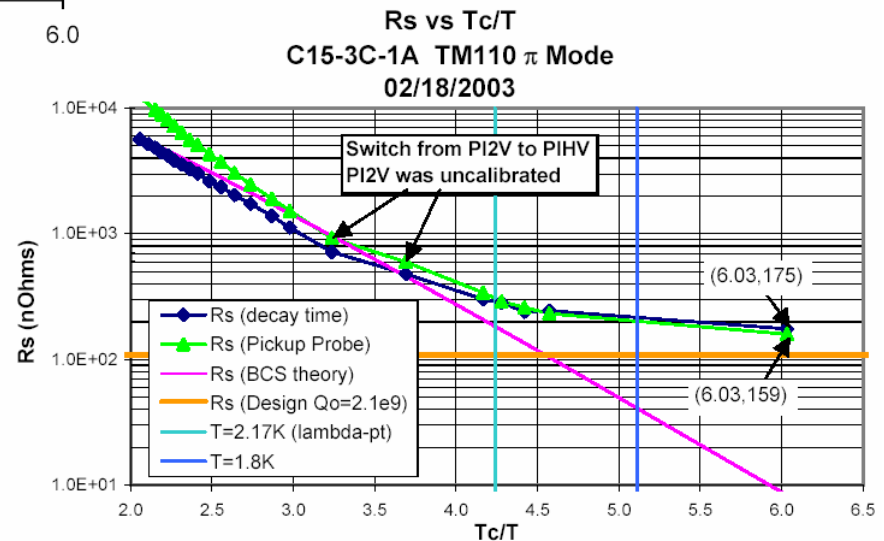
$P_{\perp}$  originally  $\sim 5.1$  MV/m but has decreased to about 3.5 MV/m with repeated tests. Have recovered 5.4 MV/m (but high  $R_{\text{surf}}$ ) with recent acid etch

$R_{\text{surf}}$  vs. T design goal is 110 n $\Omega$

Recently obtained  $\sim 160$  n $\Omega$  in TM<sub>110</sub>,  
 $\sim 65$  n $\Omega$  in TM<sub>010</sub> ( $\Leftrightarrow 126$  n $\Omega$  in TM<sub>110</sub>)

Reason is not clear:

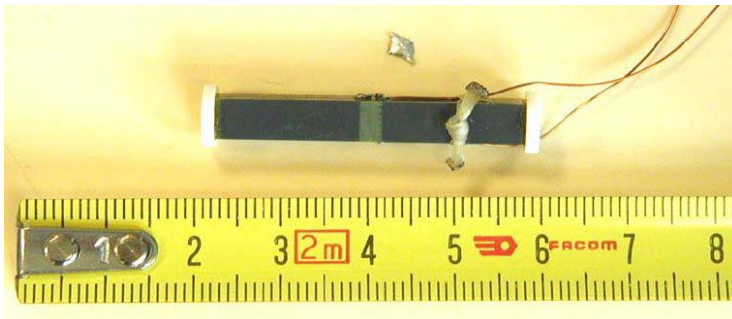
- > Residual beam pipe effect?
- > Power lost in coupler tip?
- > Power in weld area?
- > Otherwise wrong  $\kappa, R_{\text{SURF}}$ ?



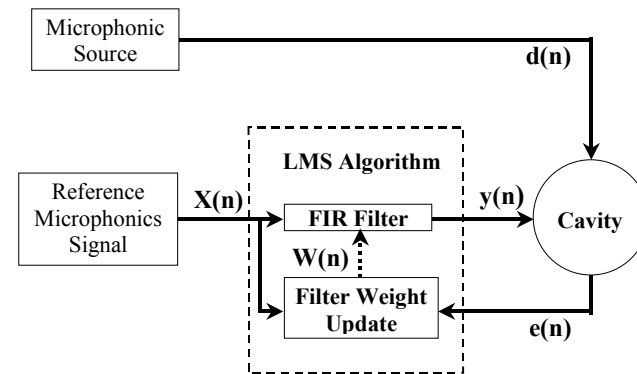
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# Piezoelectric R&D

We have been investigating the use of piezoelectric elements to dynamically adjust the length of the cavities in response to mechanical vibrations, temperature and pressure changes, etc.



At 300K: Open loop resolution	$O [10\text{nm}]$
Loads	$O [1000\text{N}]$
Range of motion	$O [10\mu\text{m}]$



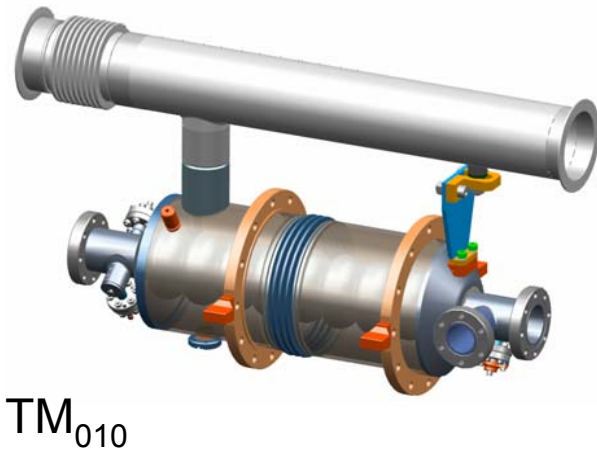
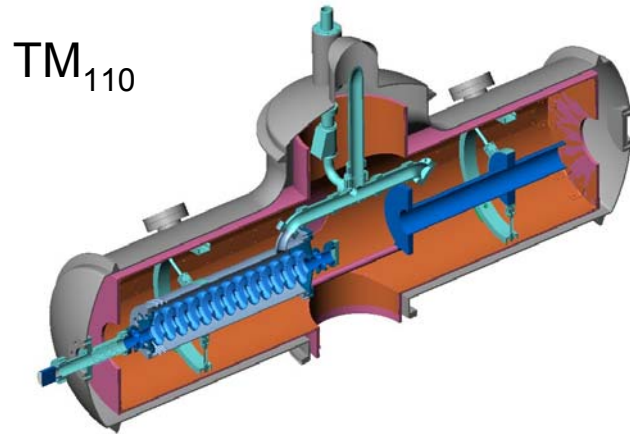
The dynamically adjusted filter tries to match the transfer function of the piezo/cavity system; output  $y(n)$  is applied so as to cancel  $e(n)$ .

For testing, another piezo is used to create sample microphonics

*Have been able to get enough canceling amplitude at selected frequencies, need to understand nonlinearities better*

# Cryovessel Design & Fabrication

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# *Conclusion*

*Carrying out the Superconducting RF cavity R&D for these two relatively modest systems has lead us to develop a wide range of design, manufacture and test facilities that provide an excellent knowledge base for any future SCRF based project.*

*Following slides are spares that  
were not shown.*





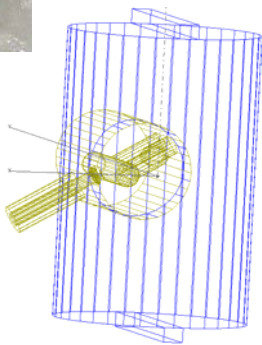
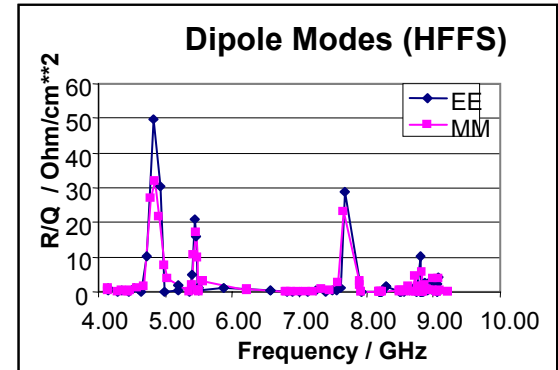
# RF Design

Higher order modes are most critical for  $TM_{010}$  cavities; for  $TM_{110}$  cavities, worst HOM is a LOM

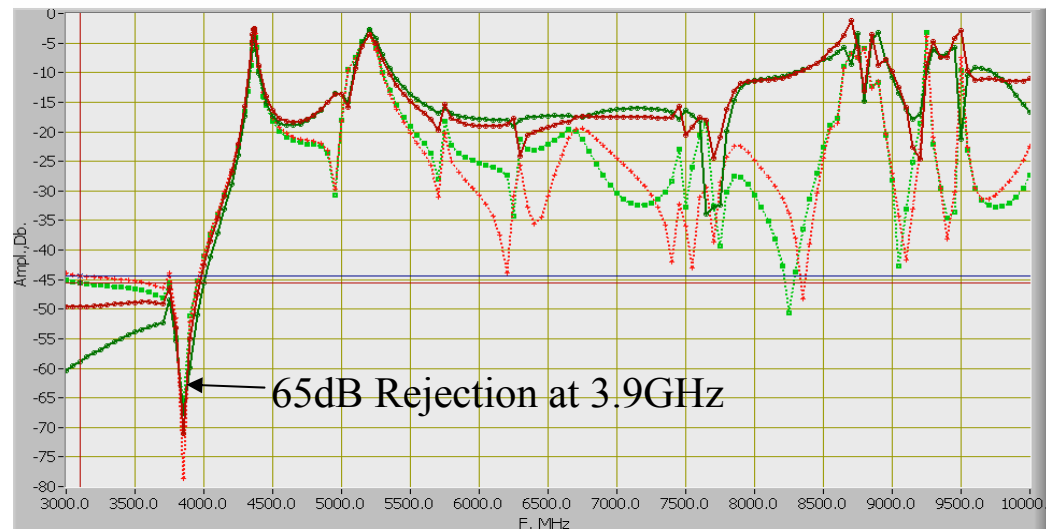
Rescaled from TESLA HOM couplers (J.Sekutowicz)

R/Q quantities calculated in collaboration with DESY, using both MAFIA and HFSS

HFSS 3D model used to study cavity excitation by beam as function of frequency



**S parameters coupler to beam pipe)**

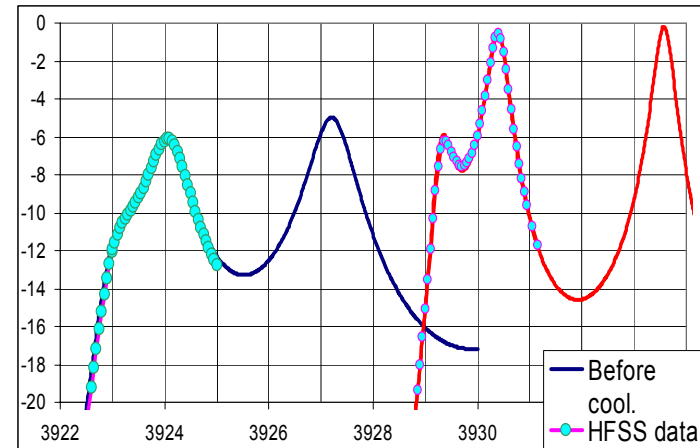
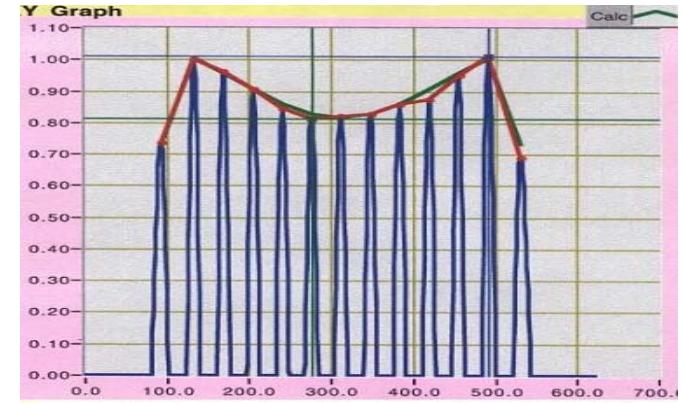


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# RF Design

## *Tuning cavities with overlapping modes*

- First prototype  $TM_{110}$  half-cells had  $\sim 600\text{MHz}$  scatter
- First cavity had  $\pi$  mode and  $(\pi-1)$  modes totally degenerate
- Designed mode separation was very close anyway
- HFSS predicts “M” type bead pull result for 300K; linear combo of MAFIA eigensolutions similar
- At 70K, HFSS gave correct  $S_{21}$  vs.  $f$  plot, and bead pull result was flatter. Plan to try bead pull at LHe temps.



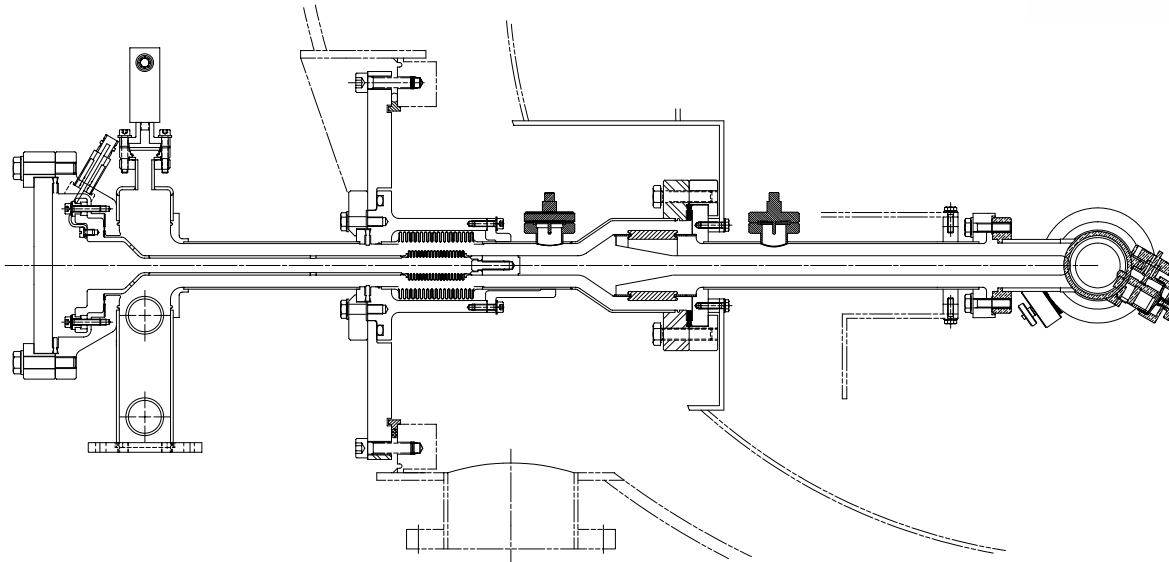
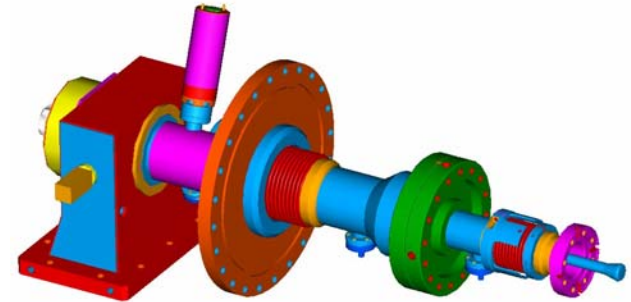
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# Power Coupler Development

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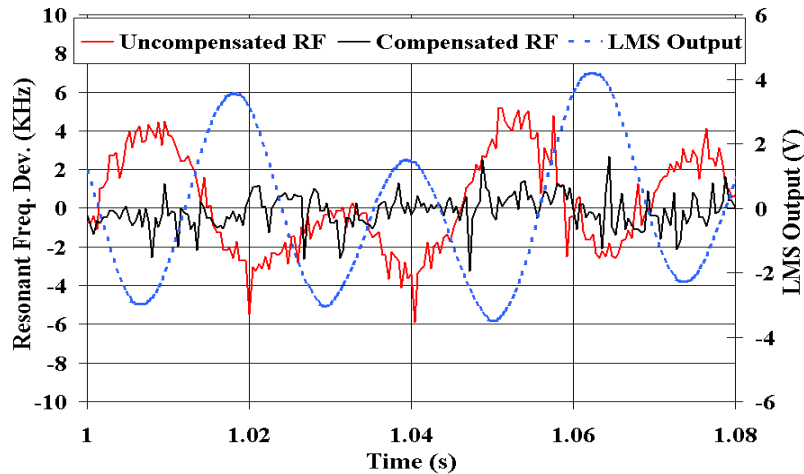
Initial design was adjustable

Plan to try a non-adjustable version with  
3-stub tuner in waveguide



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# Piezoelectric R&D

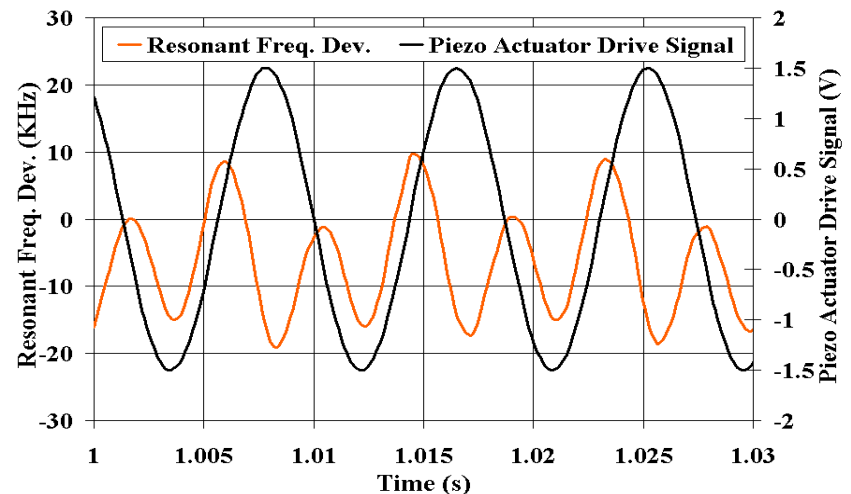


Driving the cavities with sum of three sine waves at 15Hz, 27Hz, and 45Hz, where there are known mechanical resonances to the system.

RED curve is FM modulation with algorithm off  
BLACK curve is FM modulation with algorithm on

## *Nonlinear behavior at subharmonics*

Algorithm requires linear device to be emulated, but we find that if we drive at an integer fraction of the frequency of a mechanical resonance, the piezo/cavity system is non-linear. *To be investigated*



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